Alternative Geologic Models: Their Significance with Respect to Calculation of Volcanic Hazard at Yucca Mountain

Presentation to the Nuclear Waste Technical Review Board (NWTRB)

March 8-9, 1994

Eugene I. Smith
Dept. Geoscience
University of Nevada
Las Vegas, Nevada 89154
(702) 895-3971
(702) 895-4064 FAX
eismith@nevada.edu (E-mail)

C.H. Ho
Dept. Mathematical Sciences
University of Nevada
Las Vegas, Nevada 89154
(702) 895-3494
(702) 895-4343
chho@nevada.edu (E-mail)

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Purpose

- Resolve problems regarding hazard assessment and consequence analysis
- Outline new and continuing research
- Demonstrate that these studies may make a difference.

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Outline

1. Geological studies
2. Volcanic hazard assessment

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Geological Studies

- Definition of a volcanic event
- Structural control of volcanism and area affected by future eruptions
- Explosivity of eruptions

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Definition of a Volcanic Event

- Definition is unclear
- Based on chemistry, field relations, geochronology, geographical distribution.
- Must develop a usable definition

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Volcanic Event

- A field of volcanoes formed at about the same time
- Eruption of chemically distinct magma batches
- Eruptions separated by a significant periods of time
- Count vents
- Count volcanic complexes

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A field of volcanoes formed at about the same time

Three events:

Lathrop Wells, 1.1 Crater Flat, 3.7 Crater Flat

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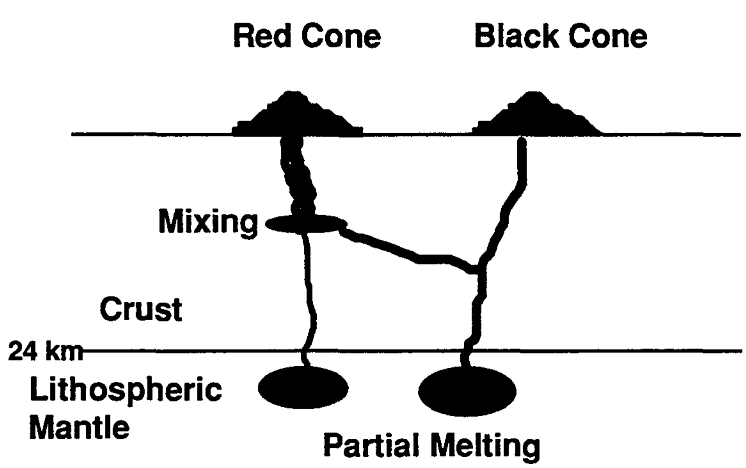
Crater Flat



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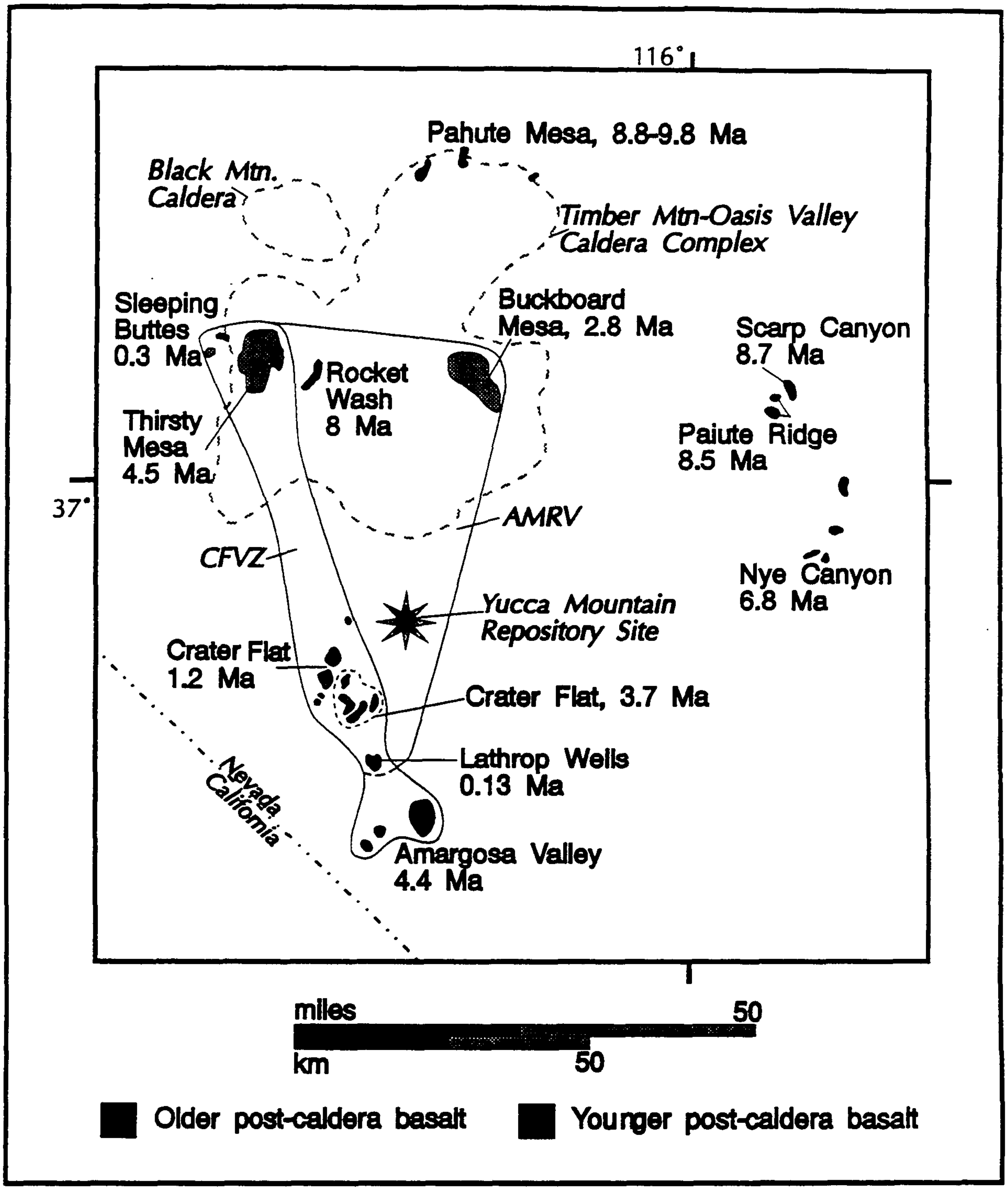
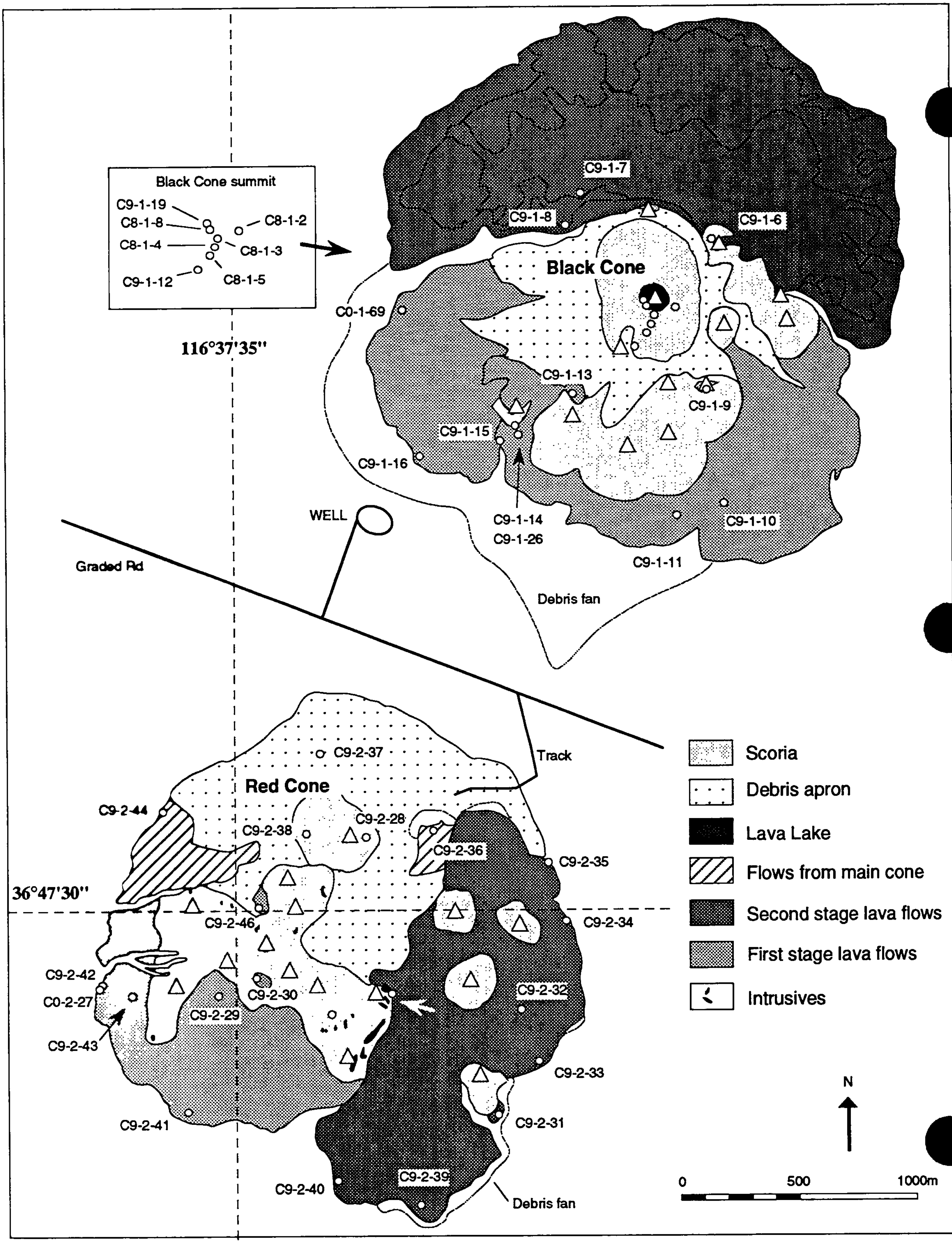
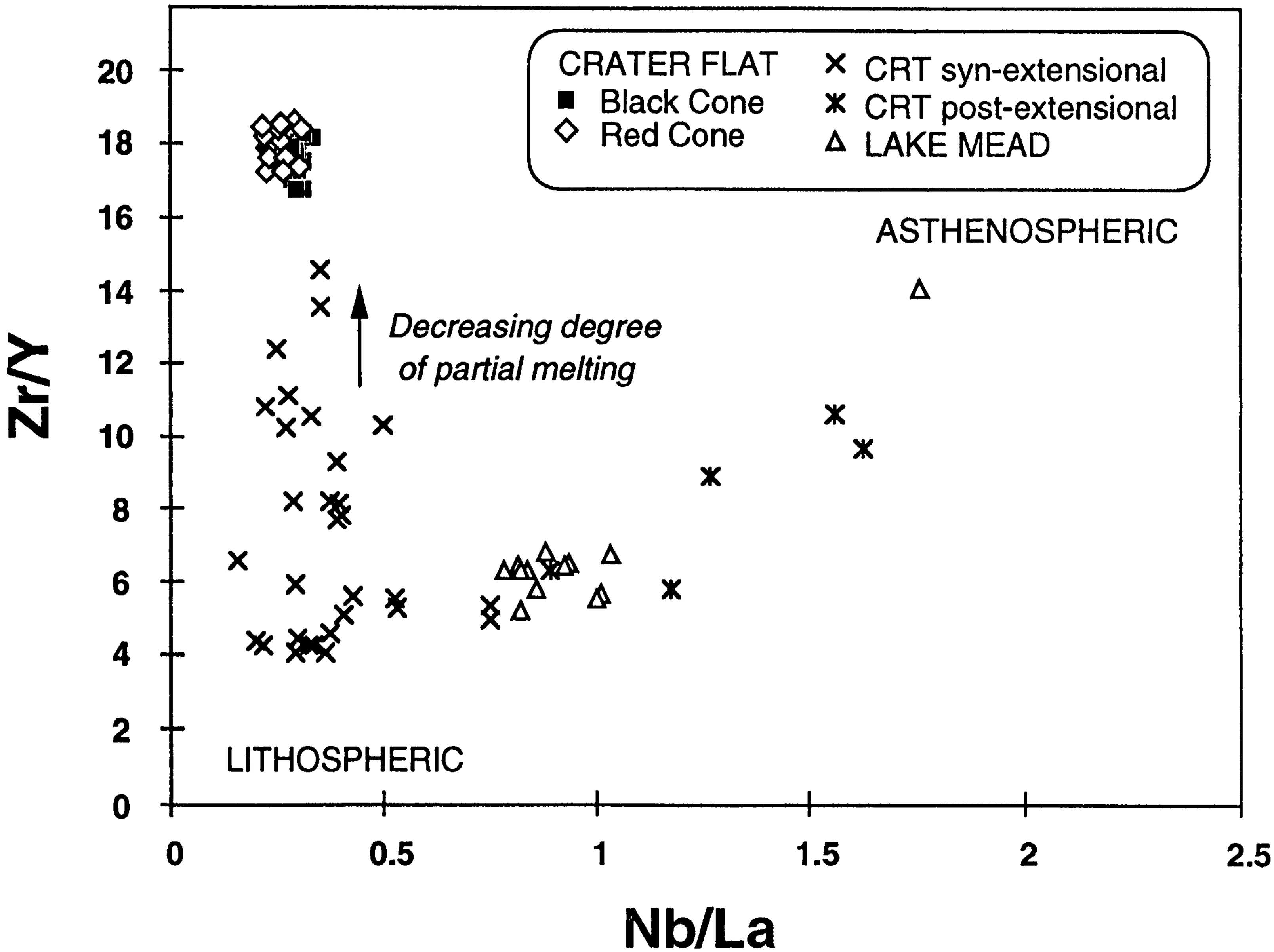


FROM:

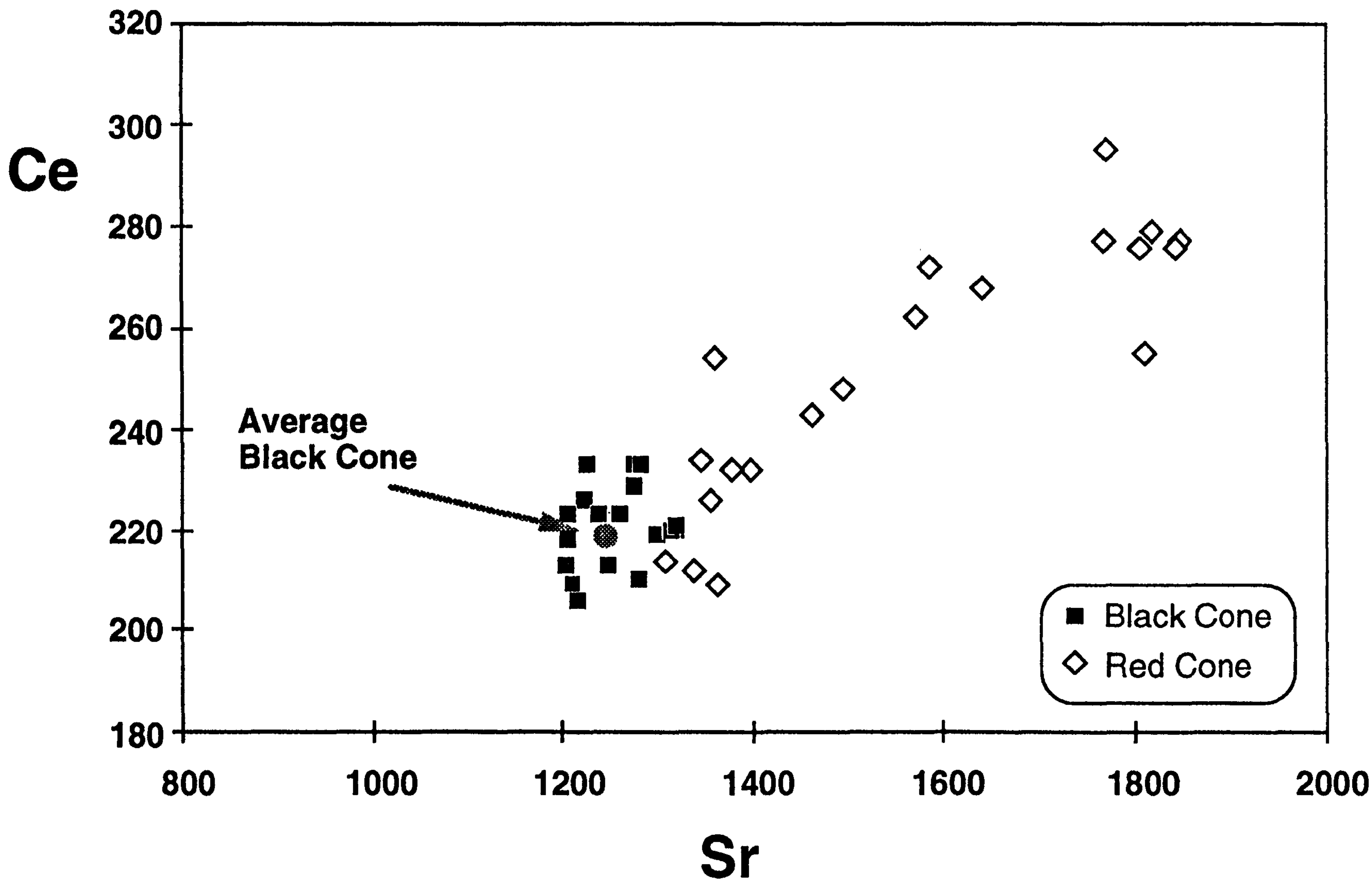
CROWE (1990)
CROWE ET AL. (1982; 1983)
VANIMAN AND CROWE (1981)
CROWE AND PERRY (1991)
CROWE (1992, WRITTEN COMMUNICATION (NWTRB))



Black Cone summit
C9-1-19
C8-1-8
C8-1-2
C8-1-4
C8-1-3
C9-1-12
C8-1-5
C9-1-7
C9-1-8
C9-1-6
Black Cone
C0-1-69
116°37'35"
C9-1-13
C9-1-9
C9-1-15
C9-1-16
C9-1-14
C9-1-26
C9-1-10
C9-1-11
WELL
Graded Rd
Debris fan
C9-2-37
Track
Red Cone
C9-2-44
C9-2-38
C9-2-28
C9-2-36
C9-2-35
36°47'30"
C9-2-46
C9-2-34
C9-2-42
C0-2-27
C9-2-30
C9-2-29
C9-2-32
C9-2-43
C9-2-33
C9-2-31
C9-2-41
C9-2-40
C9-2-39
Debris fan
Scoria
Debris apron
Lava Lake
Flows from main cone
Second stage lava flows
First stage lava flows
Intrusives
N
0
500
1000m



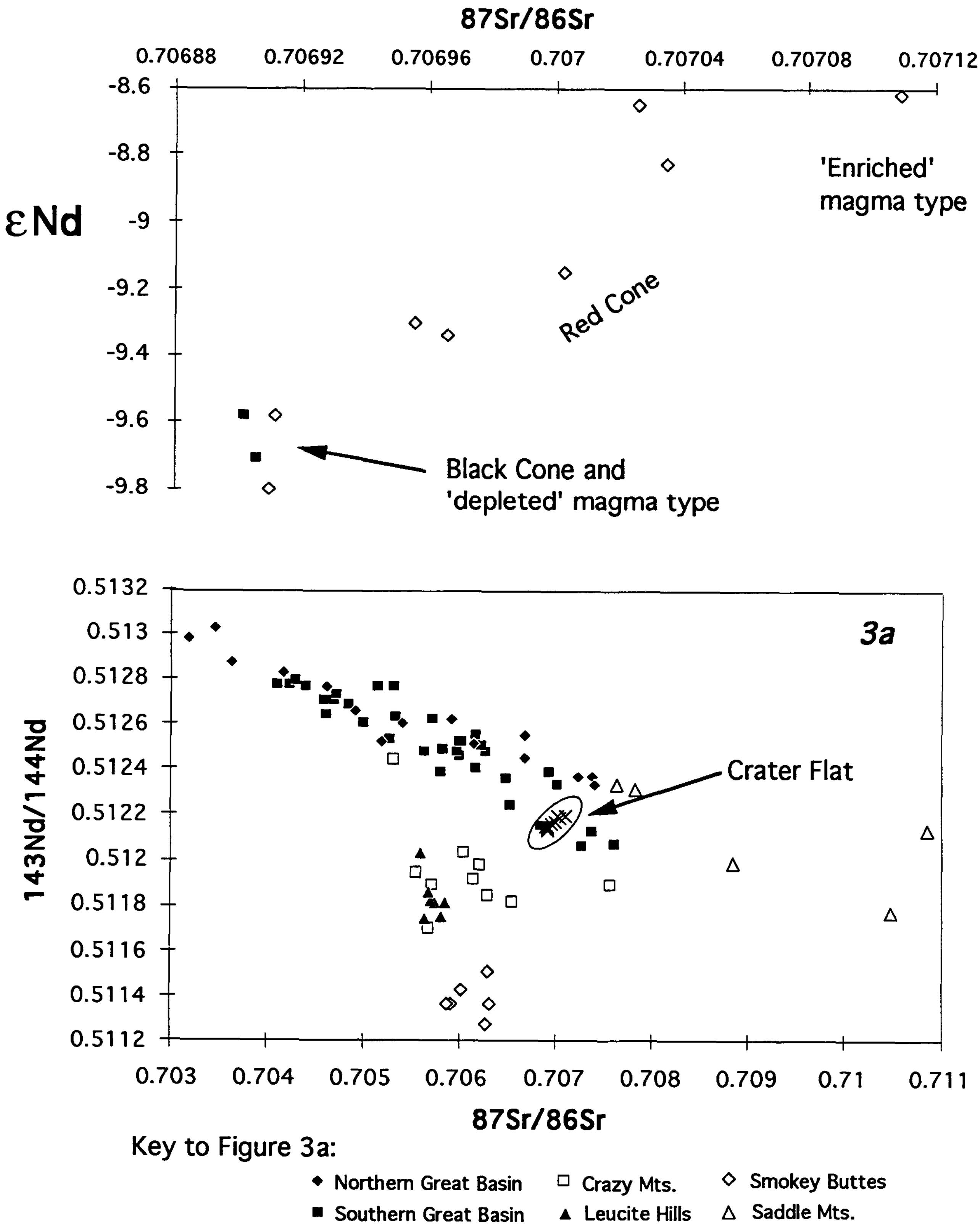
CRATER FLAT
Black Cone
Red Cone
CRT syn-extensional
CRT post-extensional
LAKE MEAD
ASTHENOSPHERIC
Decreasing degree of partial melting
LITHOSPHERIC
Zr/Y
Nb/La
0
2
4
6
8
10
12
14
16
18
20
0
0.5
1
1.5
2
2.5



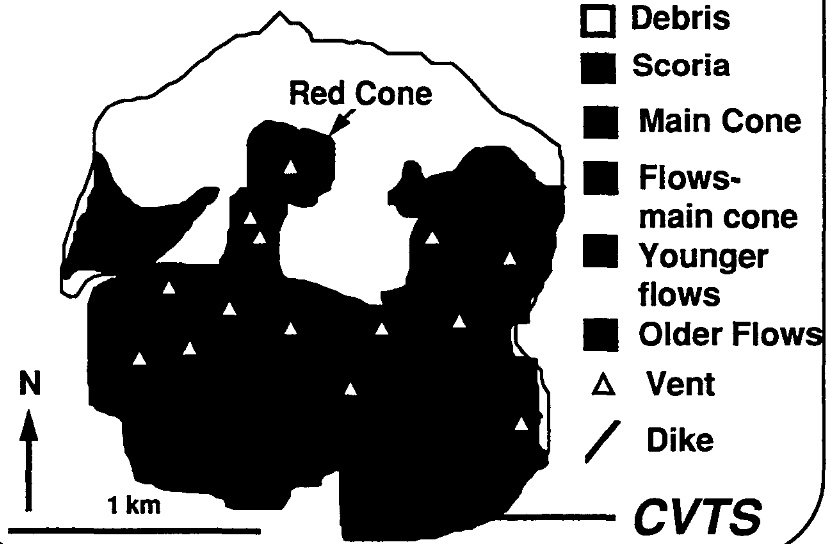
320
300
280
260
240
220
200
180
Ce
Average
Black Cone
800
1000
1200
1400
1600
1800
2000
Sr
Black Cone
Red Cone

Figure 3. Sr and Nd isotope data for samples from Crater Flat.

3a. Comparison of Crater Flat data to samples from other volcanic fields in the western United States. Note that the Crater Flat samples fall within the trend defined by other basalts from the southern Great Basin.



Red Cone



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Eruptions separated by a significant periods of time

- Red Cone = 2 events
- Black Cone = 2 events

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Eruption of chemically distinct magma batches

- Black Cone and Red Cone = 2 events

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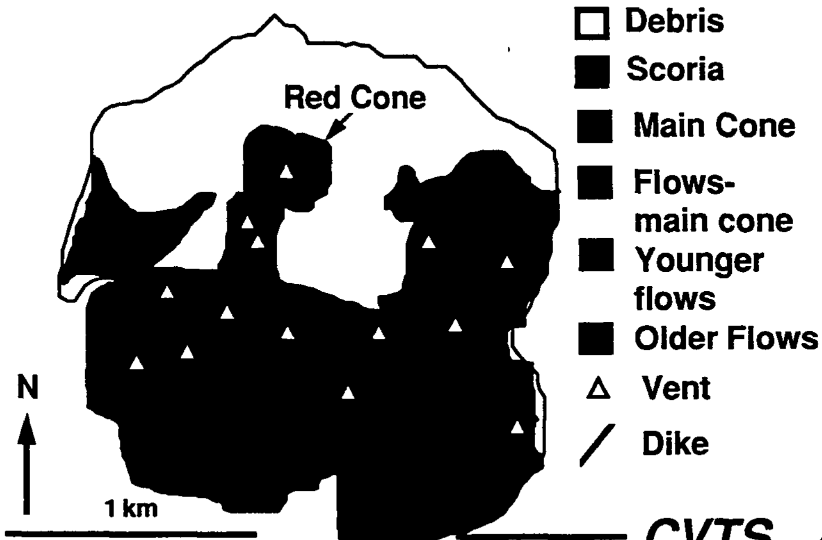
Red Cone



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Count vents

Red Cone = 14 events

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Count volcanic complexes

Red Cone = 1
Black Cone = 1

4 events in Crater Flat

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Summary

- Red Cone
  - –14 events-vent count
  - –2 events-chemistry
  - –2 events-time
  - –1 event-volcanic complex
  - –part of the Crater Flat event

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Area of Concern for Hazard Assessment

- What is the area that may be affected by a future eruption?
  - –Crater Flat zone
  - –Area of most recent volcanism
  - –Others

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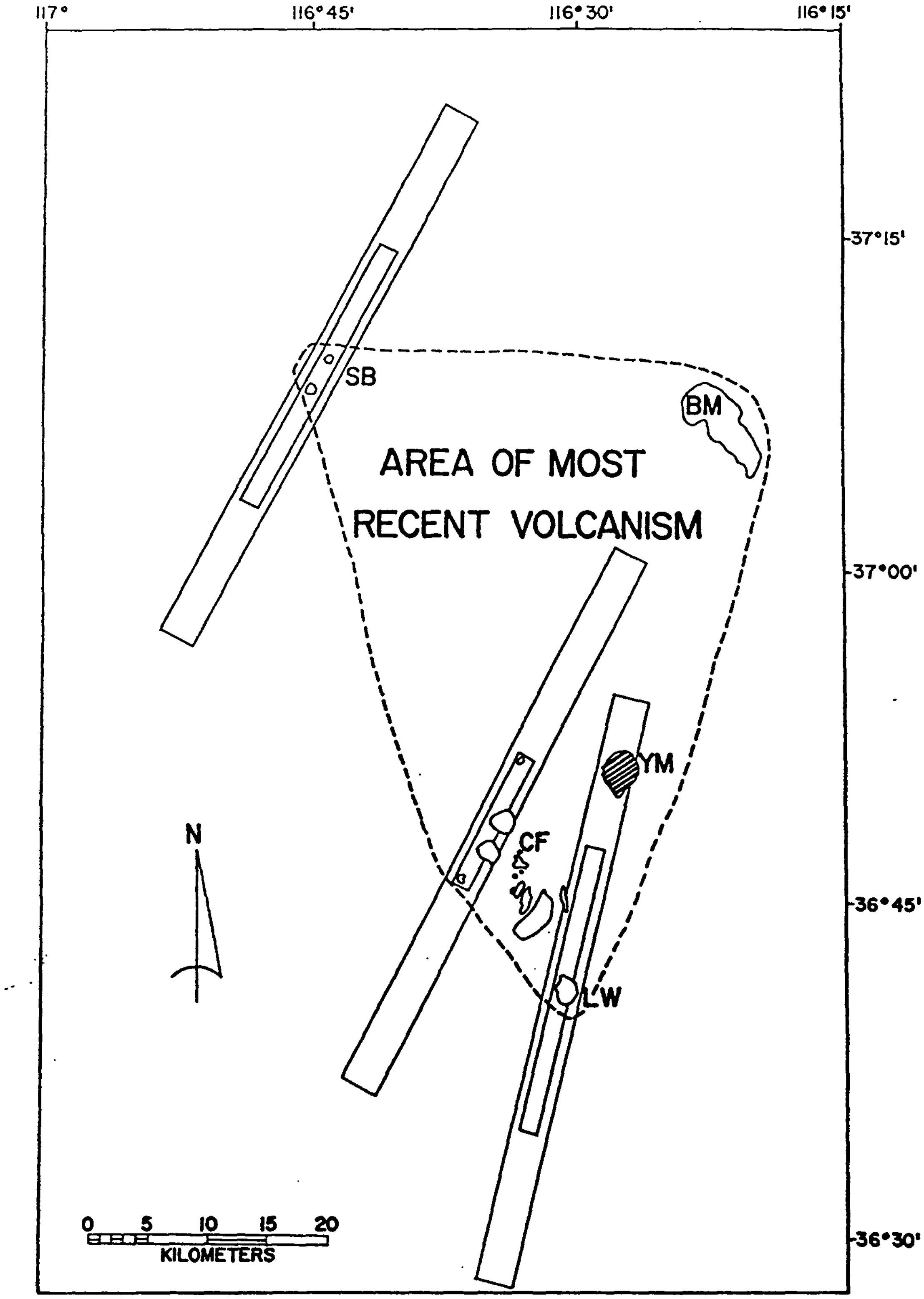

117°
116°45'
116°30'
116°15'
37°15'
37°00'
36°45'
36°30'
SB
BM
AREA OF MOST RECENT VOLCANISM
YM
CF
LW
N
0 5 10 15 20
KILOMETERS

Structural Control

- Which structures control magma emplacement in the uppermost crust?
- Formation of volcanic chains
- A single "volcanic event" may occur at more than one location.

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Consequence of Eruption

Cinder cone eruptions can be explosive (Plinian or subplinian)

For example Tolbachik in Kamchatka

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Consequence of Eruption

- Determine the explosivity of an eruption.
- Volatile content (especially H_2O) is an indication of explosivity.

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Consequence of Eruption

- Melt inclusions are quenched samples of magma (and volatile phases) at time of eruption.
- Melt inclusions occur in olivine phenocrysts in a wide variety of tectonic settings.

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Consequence of Eruption

- Compare H_2O in primitive melts at Crater Flat and Lathrop Wells with data from volcanic centers with known eruptive type.
- Similar volatile contents would be an indication but not proof of similar eruptive mechanism.
- Support with geological data.

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Summary

- Important data required for hazard assessment studies not yet available
  - volcanic event and area affected by volcanism still debated
- Cinder cones may erupt by a Plinian or subplinian mechanism

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To Quantify

The possibility of direct disruption of the respository by basaltic volcanism (an important factor in determining future public and environmental saftey).

Related Issues

1. Modeling Assumptions:
   homogeneous Poisson vs.
   nonhomogeneous Poisson
2. Eruptive History of Basaltic Volcanism:
   monogenetic vs. polycyclic
3. Structural Controls on Basaltic Volcanic Activity:
   northwest vs. northeast trend
4. Counts of Volcanic Events

BASIC MODELS

	Past	Future
1. HPP	Simple Poisson	Simple Poisson
2. WP-HPP	Weibull Process	Simple Poisson
3. WP	Weibull Process	Weibull Process

Probability of repository disruption *p*

Estimates of *p* listed in Table 7.1 of

Crowe et al. (1993) range from

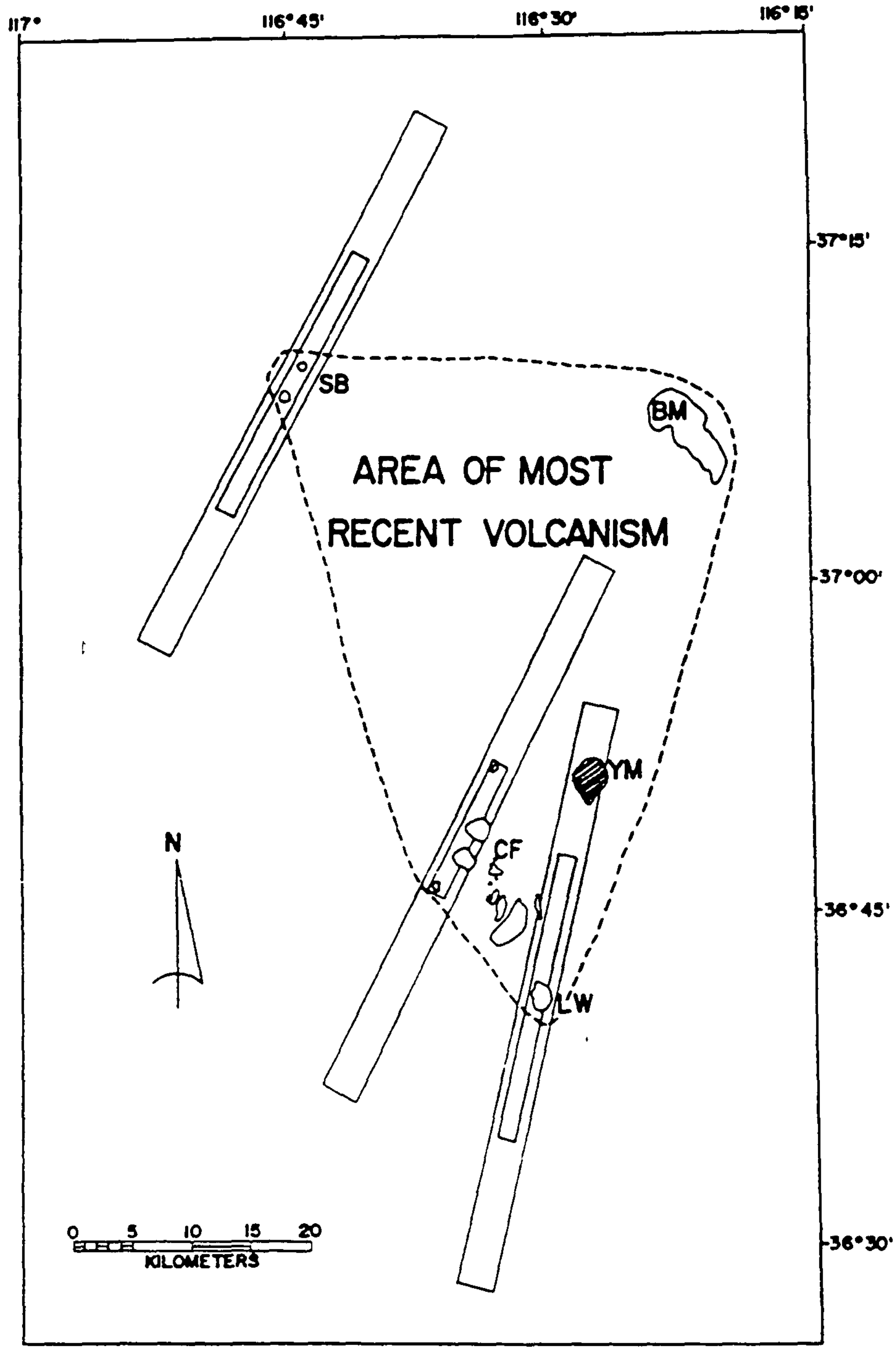
$$1.1 \times 10^{-3} \text{ to } 8 \times 10^{-2}$$

Two approaches for *p*

Classical — $p = 1.1 \times 10^{-3}$

Classical — $p = 8 \times 10^{-2}$

Bayesian — $p \sim U(0, 8/75)$



Map outlining the AMRV (dashed line) and high-risk zones (rectangles) in the Yucca Mountain (YM) area that include Lathrop Wells (LW), Sleeping Butte cones (SB), Buckboard Mesa center (BM), volcanic centers within Crater Flat (CF). (Source: Smith et al., 1990 , fig. 7)

We have

1. $A = 75\ km^2$ (= half of the rectangle)

2. $a = 8\ km^2$ (area of the respository, Crowe et al, 1982)

3. $\pi(p) \sim U(0,8/75)$, which assumes 8/75 as the upper limit for p

Model	Approach	Parameter
HPP	Classical	$p = 1.1 \times 10^{-3}$
		$p = 8 \times 10^{-2}$
	Bayesian	$p \sim U(0, 8/75)$
WP-HPP	same as above	
WP		

DATA (Crowe et al. 1993)

4.6 Ma, Thirsty Mesa (1 to 3 events)

4.4 , Amargosa Valley

3.7 , Crater Flat (1 to 5 events)

2.9 , Buckboard Mesa

1.1 , Crater Flat (4 to 6 events)

0.38 , Sleeping Butte (2 events)

0.1 , Lathrop Wells

0.01 , Lathrop Wells (remains controversial)

- **Post-6-Ma** (Pliocene and younger, 90 data sets)

4.6 (1 to 3), 4.4, 3.7 (1 to 5), 2.9, 1.1 (4 to 6), 0.38 (2), 0.1, 0.01 (0 to 1).

- **Quaternary, 6 data sets**

1.1 (4 to 6), 0.38 (2), 0.1, 0.01 (0 to 1)

Notes

Risk: probability of at least one disruptive event over the next 10,000 years $(= t_0)$ years

Model	Classical	Bayesian
HPP, WP-HPP	$1 - \exp\{-\lambda p t_0\}$	$1 - \int_p \exp\{-\lambda p t_0\}\pi(p)dp$
WP	$1 - \exp\{-m(t_0)p\}$	$1 - \int_p \exp\{-m(t_0)p\}\pi(p)dp$

Table 1 **Results of the sensitivity analysis for the proposed Yucca Mountain Repository site based on the data of Quaternary volcanism**

Model	Recurrence rate (min, max)	Risk		
		Classical $p = 1.1 \times 10^{-3}$	Classical $p = 8 \times 10^{-2}$	Bayesian
HPP	$(4.38 \times 10^{-6}, 6.25 \times 10^{-6})$	$(4.81 \times 10^{-5}, 6.87 \times 10^{-5})$	$(3.49 \times 10^{-3}, 4.99 \times 10^{-3})$	$(2.33 \times 10^{-3}, 3.33 \times 10^{-3})$
WP-HPP	$(5.83 \times 10^{-6}, 8.23 \times 10^{-6})$	$(6.40 \times 10^{-5}, 9.06 \times 10^{-5})$	$(4.65 \times 10^{-3}, 6.56 \times 10^{-3})$	$(3.10 \times 10^{-3}, 4.38 \times 10^{-3})$
WP	$(5.83 \times 10^{-6}, 8.23 \times 10^{-6})$	$(6.41 \times 10^{-5}, 9.06 \times 10^{-5})$	$(4.65 \times 10^{-3}, 6.57 \times 10^{-3})$	$(3.10 \times 10^{-3}, 4.38 \times 10^{-3})$

Table 2. Results of the sensitivity analysis for the proposed Yucca Mountain Repository site based on the data of Pliocene and younger volcanism

Model	Recurrence rate (min, max)	Risk		
		Classical $p = 1.1 \times 10^{-3}$	Classical $p = 8 \times 10^{-2}$	Bayesian
HPP	$(1.83 \times 10^{-6}, 3.33 \times 10^{-6})$	$(2.02 \times 10^{-5}, 3.67 \times 10^{-5})$	$(1.47 \times 10^{-3}, 2.66 \times 10^{-3})$	$(9.77 \times 10^{-4}, 1.78 \times 10^{-3})$
WP-HPP	$(3.41 \times 10^{-6}, 5.67 \times 10^{-6})$	$(3.75 \times 10^{-5}, 6.24 \times 10^{-5})$	$(2.72 \times 10^{-3}, 4.53 \times 10^{-3})$	$(1.82 \times 10^{-3}, 3.02 \times 10^{-3})$
WP	$(3.41 \times 10^{-6}, 5.67 \times 10^{-6})$	$(3.75 \times 10^{-5}, 6.24 \times 10^{-5})$	$(2.72 \times 10^{-3}, 4.53 \times 10^{-3})$	$(1.82 \times 10^{-3}, 3.02 \times 10^{-3})$

1. How models and data affect calculation of volcanic risk?
2. Is the difference significant?
3. How important is the related future work?

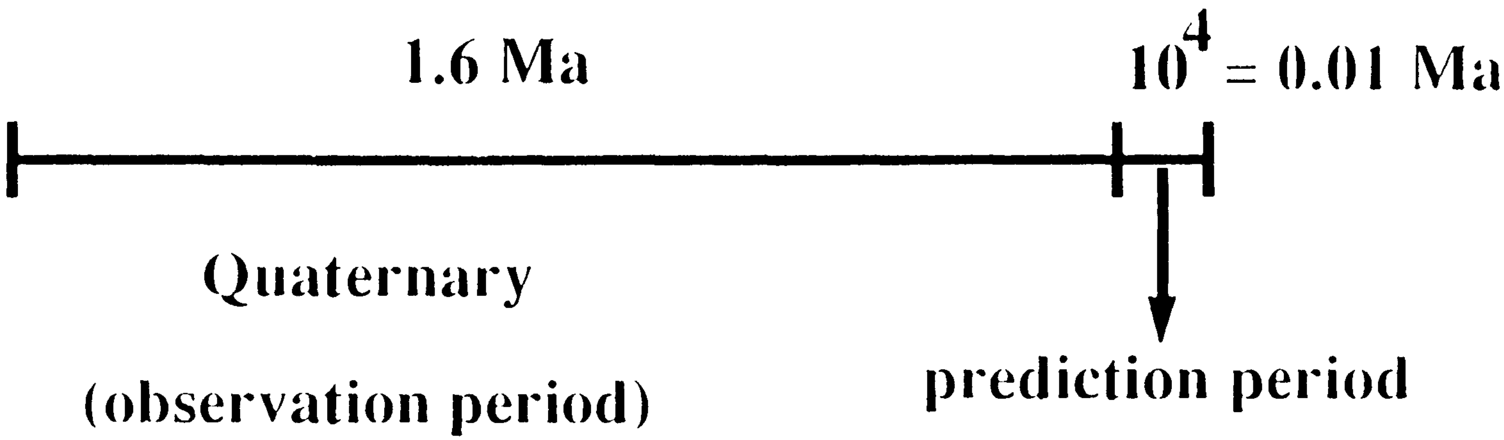
1. - Recurrence rate and risk are higher based on the Quaternary data.

   - Reason: length of the Pliocene period outweighs the greater number of events.

2.• (Instantaneous) recurrence rates produced by the WP are generally higher than rates obtained from the HPP, which shows that the volcanic trend is increasing.

3. - The classical approach using $p = 1.1 \times 10^{-3}$ and $p = 8 \times 10^{-2}$ yields the lowest and the highest values respectively for the risk.
- The Bayesian approach yields risks that are of the same order of magnitude as those calculated using the higher p.

4. • Results of both WP & WP-HPP models are almost identical.



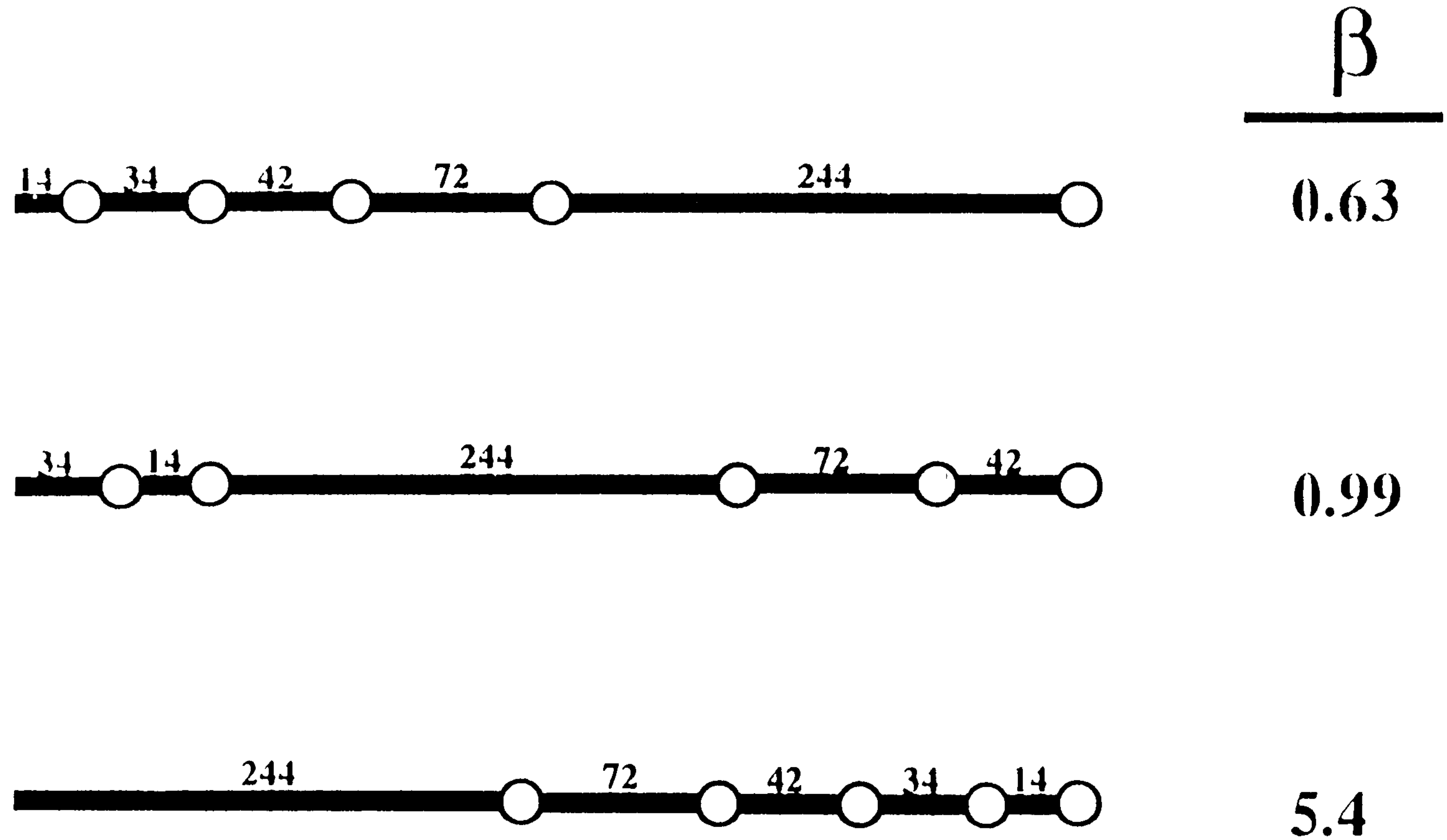
1. The projected time frame is about 0.6% of the OP
2. It is only 5% of the average repose time

⇓

Suggests switching from a NHPP to a predictive HPP model

5. • Inclusion of the potential youngest volcanic event at Lathrop Wells (= 10 ka) increases the risk.

- Should further young events be determined at Lathrop Wells or other sites in the AMRV, all risk values would increase, but those from the WP and WP-HPP models could change proportionally more than those from the HPP as the evidence of increasing trend is strengthened.


β
14 34 42 72 244
0.63
34 14 244 72 42
0.99
244 72 42 34 14
5.4

6. • As expected, data with the least (most) count of events yield the lowest (highest) values of both recurrence rate and risk using the model of HPP.

- **The data set which produces the lowest risk (WP and WP-HPP models only) is: 4.6, 4.6, 4.6, 4.4, 3.7, 2.9, 1.1, 1.1, 1.1, 1.1, 0.38, 0.38, 0.1 ($\hat{\beta} = 1.57$). The risk is actually higher if we only count one event for the Basalt of the Thirsty Mesa (= 4.6 Ma) and keep the same counts for the others (in this case, $\hat{\beta} = 2.05$).**

- **Along the same line of argument, the data set which produces the highest risk is: 4.6, 4.4, 3.7, 2.9, 1.1, 1.1, 1.1, 1.1, 1.1, 1.1, 0.38, 0.38, 0.1, 0.01** $\left(\hat{\beta} = 2.43\right)$.

MAJOR RESULT

The estimated probability of direct site disruption by basaltic volcanism over the next 10,000 years is

$$2.02 \times 10^{-5} \text{ to } 6.57 \times 10^{-3}$$

What would be the effect of increasing the time period of concern for post-closure performance from 10,000 to 100,000 years?

It would increase the estimates to approximately

$$2.02 \times 10^{-4} \text{ to } 6.57 \times 10^{-2}$$

or

$$0.02\% \text{ to } 6.57\%$$

When is "enough is enough?"

What are the criteria for that determination?

Question(s) to be answered:
Are probabilities 0.02% and 6.57% both acceptable?
i.e.,
Is the difference significant?